Development of Superconducting Accelerator with ERL for EUV-FEL

KEK, High Energy Accelerator Research Organization
Japan

SRF team / ERL-EUV feasibility study Group

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ERL-EUV feasibility study Group

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The feasibility study has been done under collaboration with a Japanese company.

In this Workshop,

R. Hajima (JAEA);

"Design of high power free electron Lasers for EUV lithography applications"

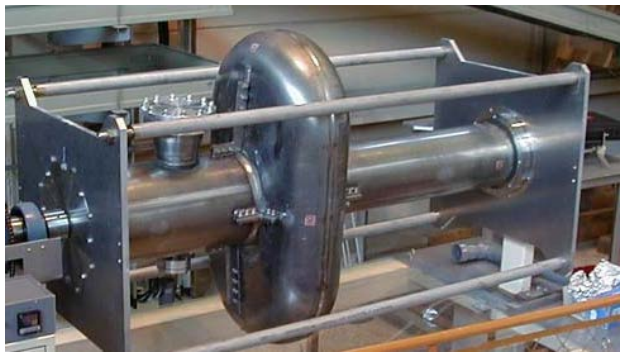
Outline

1. Introduction – SRF activities at KEK
2. ERL for EUV-FEL
3. Toward Realizing SRF Accelerator for EUV
4. Construction Plan of Prototype ERL/EUV-FEL
5. Summary

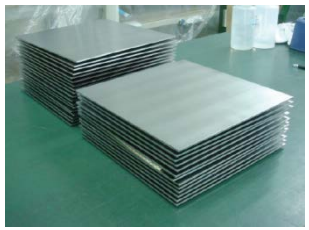
1. Introduction – SRF activities at KEK

Tristan 508MHz 5-cell Cavity

KEKB 508MHz
1-cell Cavity

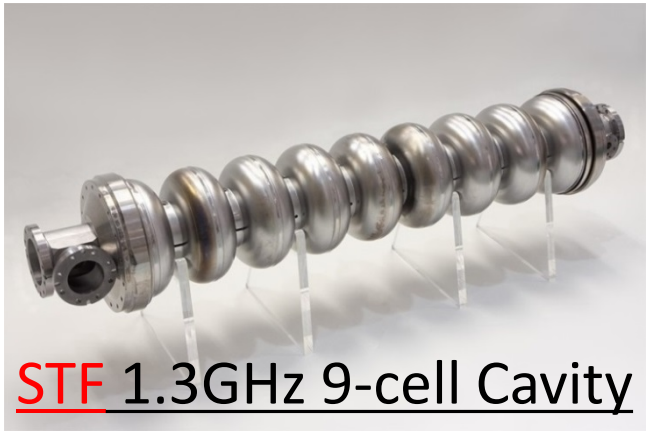


KEKB 508MHz
Crab Cavity



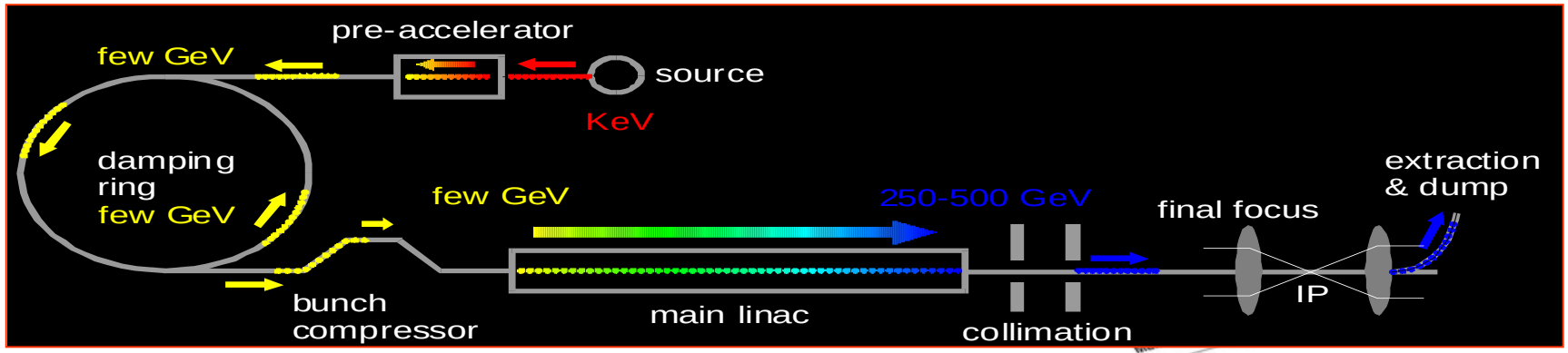
cERL Injector
1.3GHz 2-cell Cavity

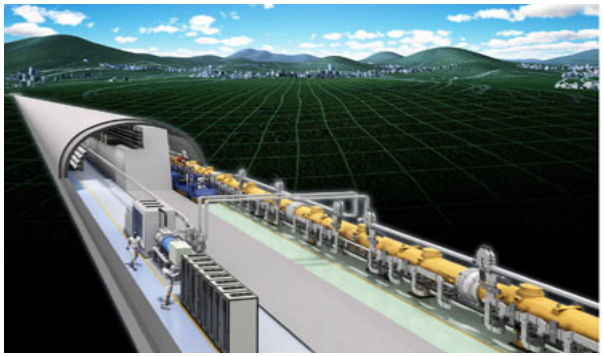
cERL ML
1.3GHz 9-cell Cavity

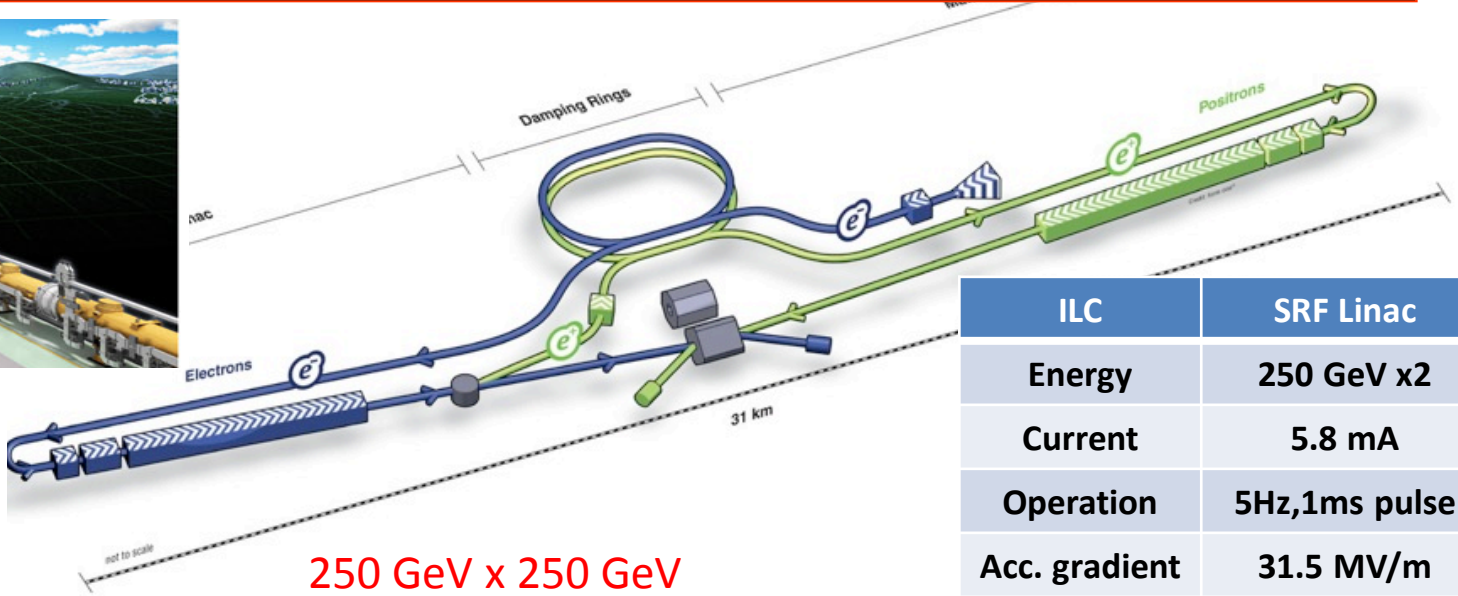


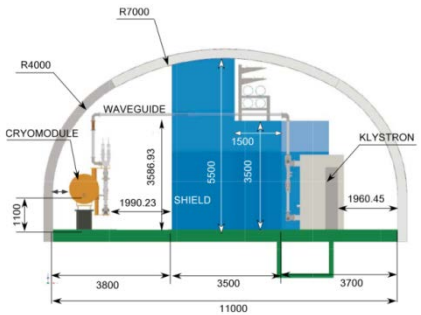
STF 1.3GHz 9-cell Cavity

ILC (International Linear Collider)







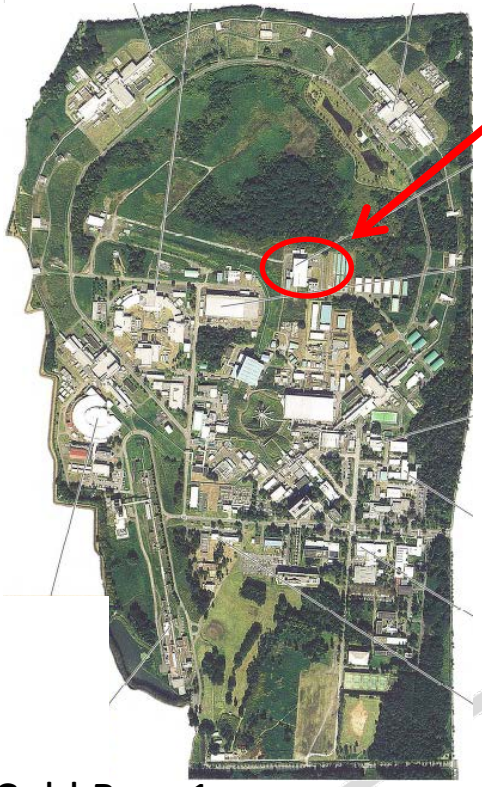


250 GeV x 250 GeV

Total tunnel length : 31 km

ILC	SRF Linac
Energy	250 GeV x2
Current	5.8 mA
Operation	5Hz,1ms pulse
Acc. gradient	31.5 MV/m
No. of cavity	16,000
No. module	1,800 (9 cav.)

STF2 for future ILC



STF Hall : Superconducting RF Test Facility

STF2 Accelerator

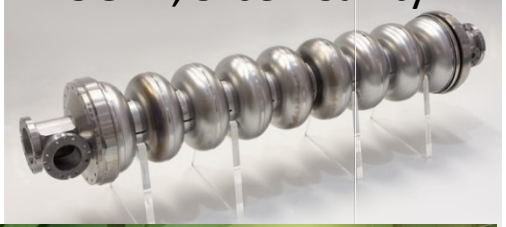
12 kW

2014' Oct.
First cool-down

CM2a Cryomodule
(four 9-cell cavities)
(Eacc = 32 MV/m)

400 MeV

1.3GHz, 9-cell Cavity



Cold Box -2

CM1 Cryomodule
(eight 9-cell cavities)
(Eacc = 32 MV/m)

40 MeV

Capture Cryomodule
(two 9-cell cavities)
(Eacc = 20 MV/m)

Cold Box -1

3 MeV

Photocathode RF-Gun:
(1.3 GHz, 6 mA, 1 ms, 5 Hz)

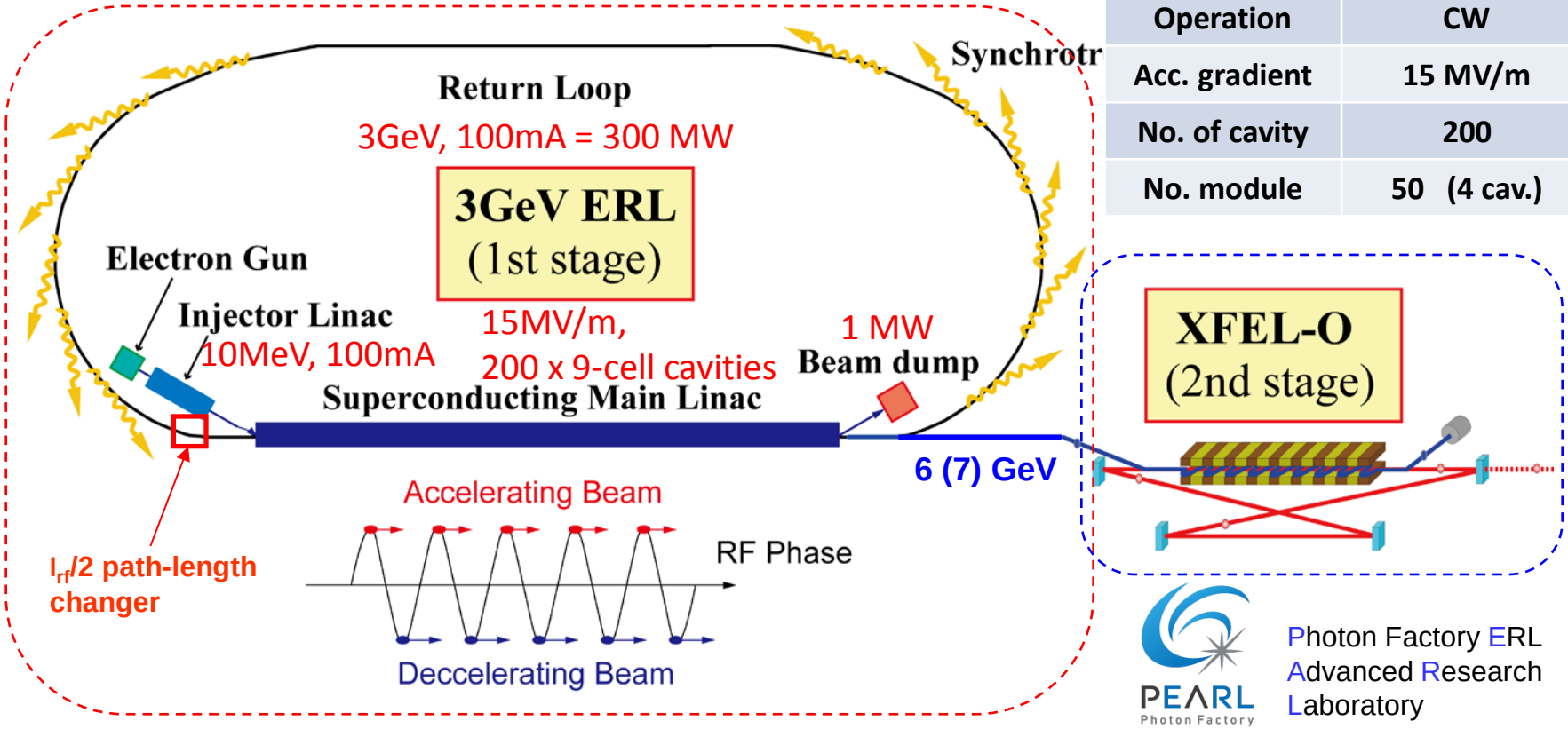
ERL (Energy Recovery Linac)

ERL-based Light Source Project at KEK (2 Stages)

① 3-GeV ERL as X-ray and VUV SR source

② 6-7 GeV XFEL Oscillator

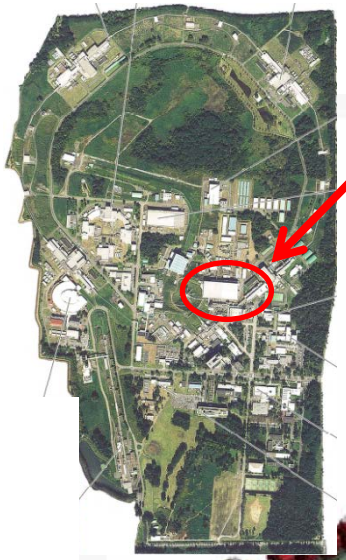
ERL	SRF Linac
Energy	3 GeV
Current	100 mA
Operation	CW
Acc. gradient	15 MV/m
No. of cavity	200
No. module	50 (4 cav.)



PEARL Photon Factory

Photon Factory ERL Advanced Research Laboratory

cERL for future 3GeV-ERL



ERL R&D Hall : Energy Recovery Linac

2014' March, Beam operation

Compact-ERL

Beam Dump
50 kW
(5 MeV, 10mA)

Recirculation loop

Injector diagnostic line

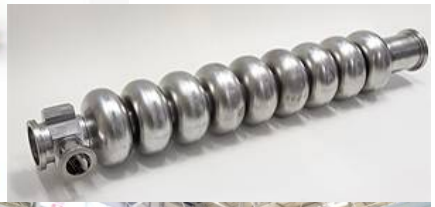
35 MeV
Main-linac module
(two 9-cell cavities)
(Eacc = 15 MV/m)

Merger

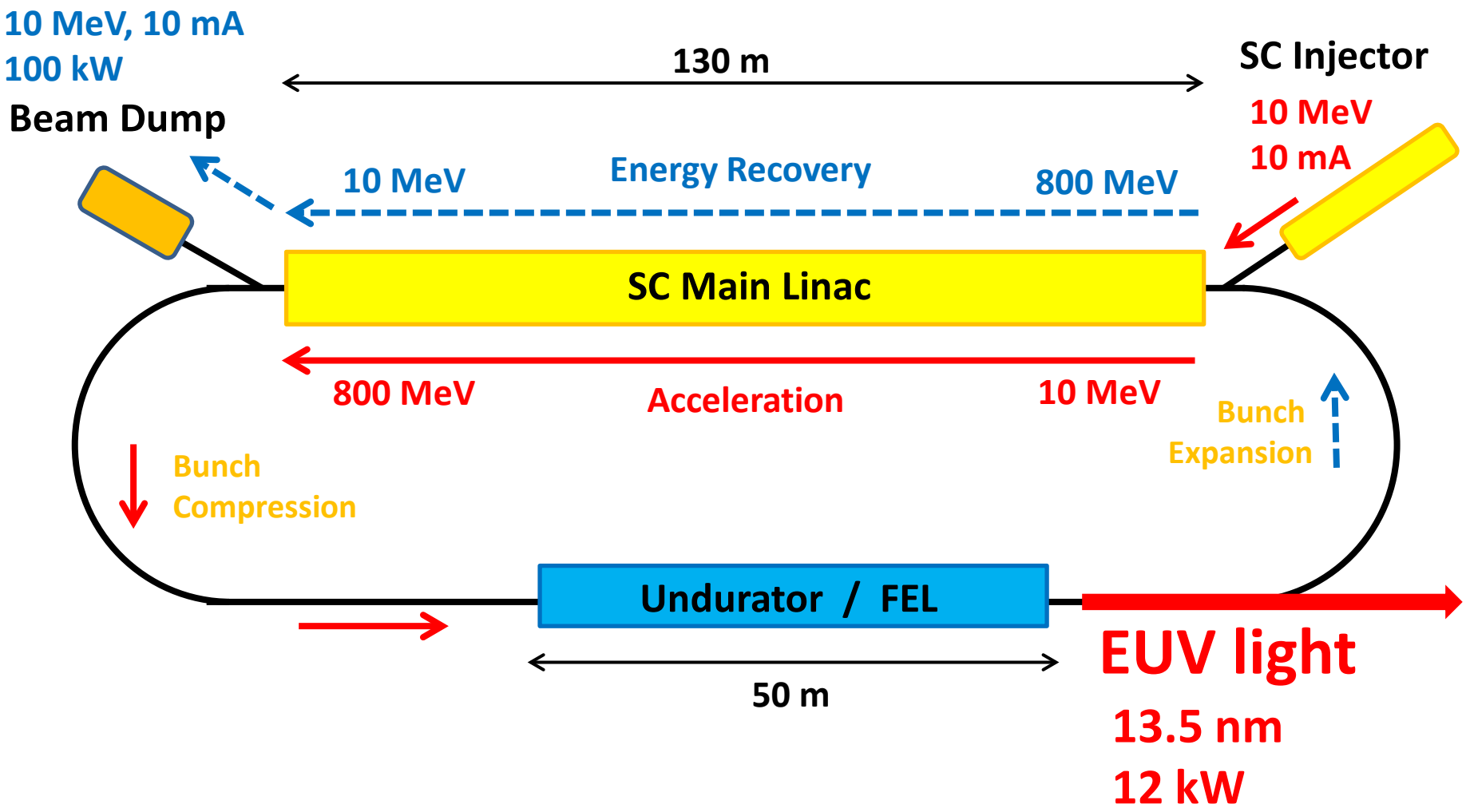
5 MeV
Injector module
(three 2-cell cavities)
(Eacc = 7.5 MV/m)

(c)Rey.Hori/KEK

0.5 MeV
Photocathode DC gun
(500 kV, CW, 10 mA)



2. ERL for EUV-FEL



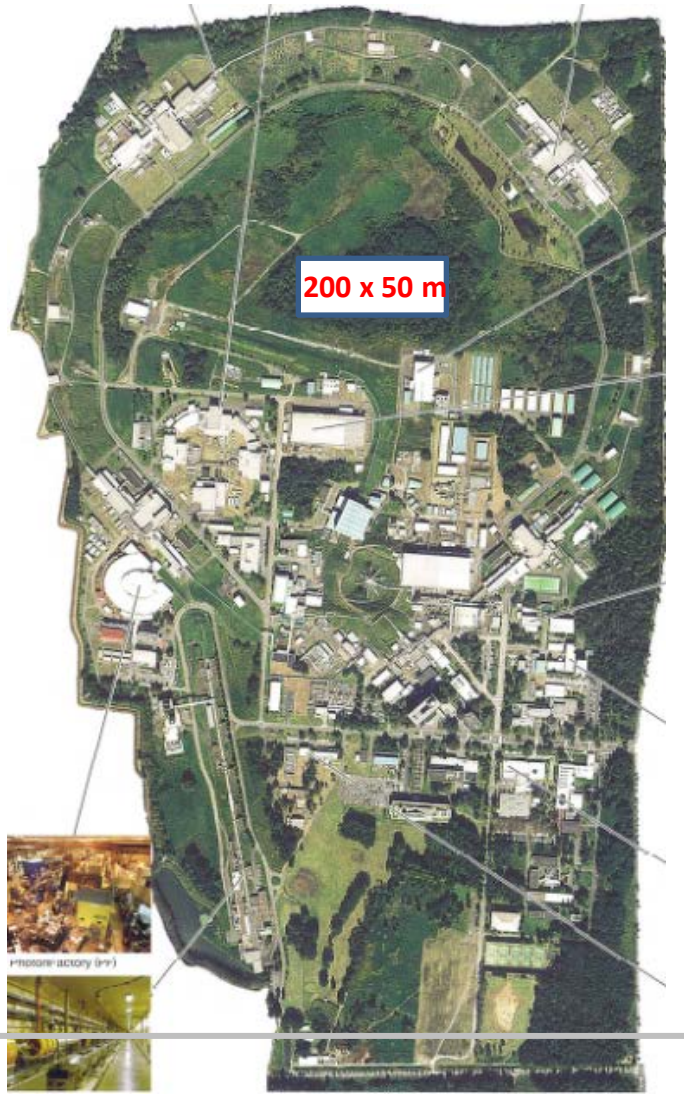
ERL Parameters for EUV/FEL

ERL	EUV/FEL
Injection Energy	10 MeV
Beam Energy	800 MeV
Bunch Charge	100 pC
Repetition Rate	81.25 MHz
ave. Current	8.125 mA
Energy Spread	0.1% rms
Normarised Emittance	0.8 mm.mrad
Undurator Gap	10 mm
EUV wavelength	13.5 nm
EUV output power	12 kW

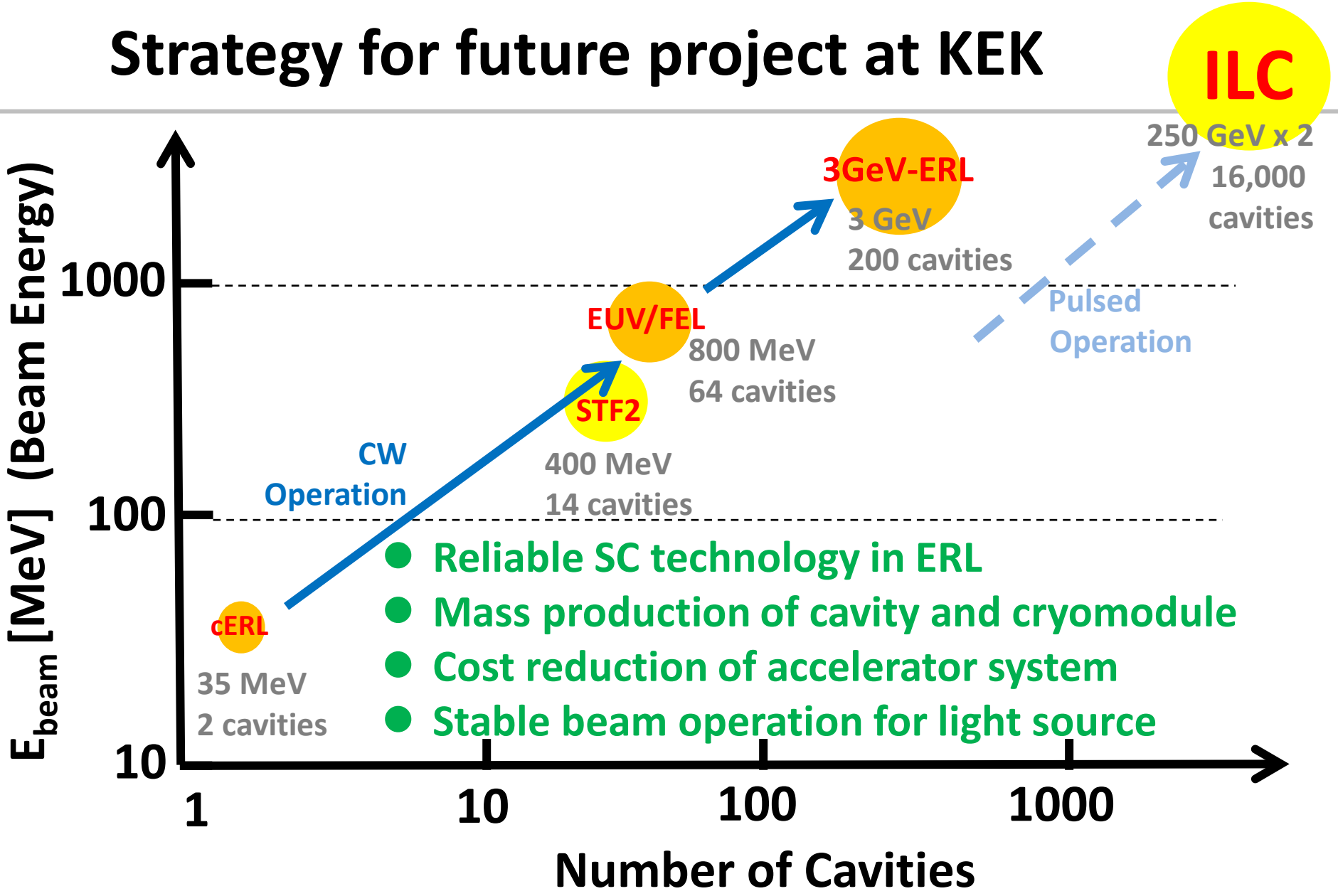
Accelerator Parameters for ERL

ERL	Main LINAC
Beam Energy	800 MeV
ave. Current	8.125 mA
Accelerating Gradient	12.5 MV/m
No. of Cavity	64
No. of Cryomodule	16 (4 cav./module)
Linac Length	130 m (Pac. Fac. 50%)
RF Power per cavity	2 kW (Q_{in}= 2x10^7)
Beam Dump Power	81 kW
Cavity Loss at 2K	1.0 kW (Qo= 1x10^{10})
Cryogenic Plant	7.0 kW (at 4K)

KEK Tsukuba Campus



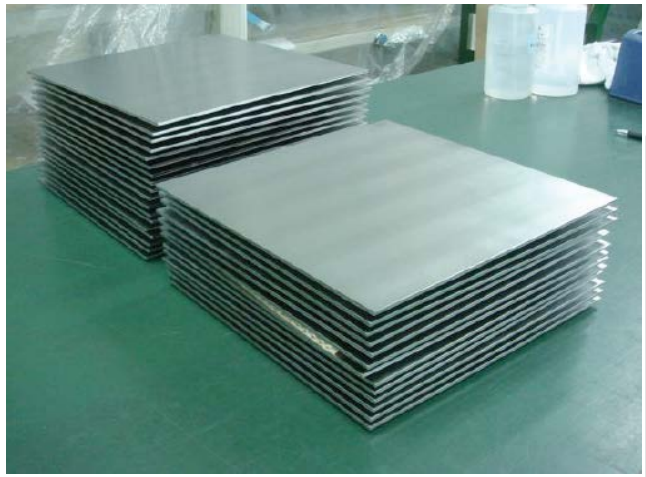
Strategy for future project at KEK



R&D issues for ERL/EUV Cryomodule

- **Optimum design** of cell-shape, He-jacket and cryomodule structure fitted for EUV light source are absolutely necessary.
- Construction and cool-down tests of **a proto-type cryomodule** including four 9-cell cavities are the most important R&D task.
- **HOM absorbers** are a key R&D components.
- Surface preparation and performance tests at low temperature of the cavities are available at infrastructures in STF.
- High power tests of the assembled cryomodules are carried out after on-site installation in an accelerator beam line.
- Selection of a **construction site** of ERL/EUV accelerator, ordering of a **cryogenic system** and purchase of all **Nb sheets** should be decided in the starting stage of the project to keep the schedule.

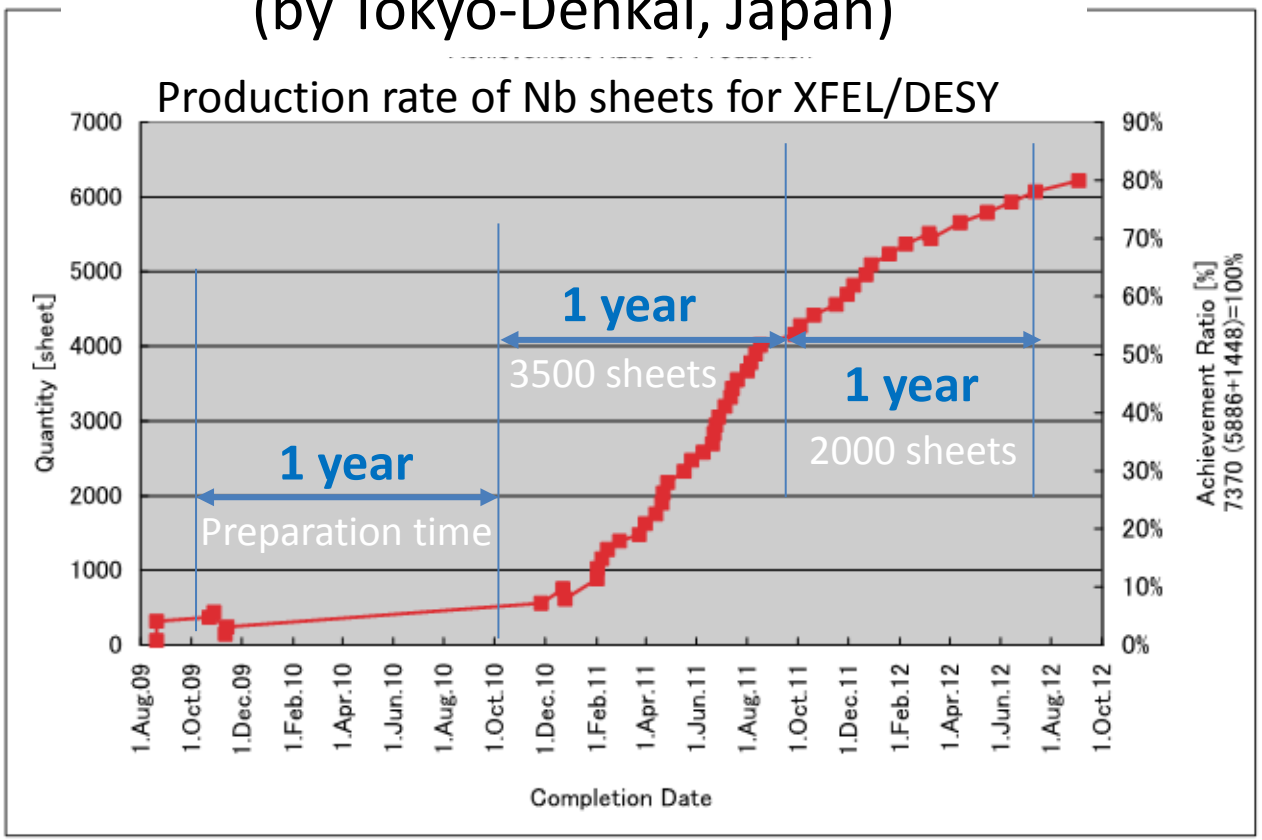
3. Toward Realizing SRF Accelerator for EUV



H. Umezawa,
TTC-meeting at JLab, USA
(Nov., 2012)

High Purity Niobium Material

(by Tokyo-Denkai, Japan)



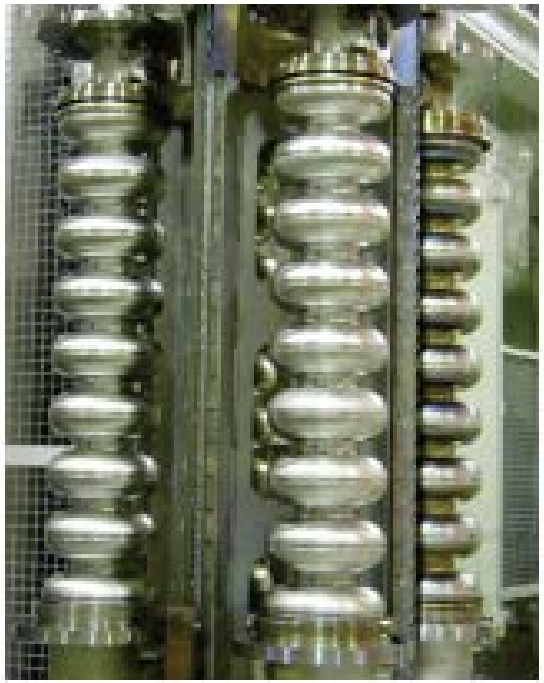
18 sheets / 9-cell cavity

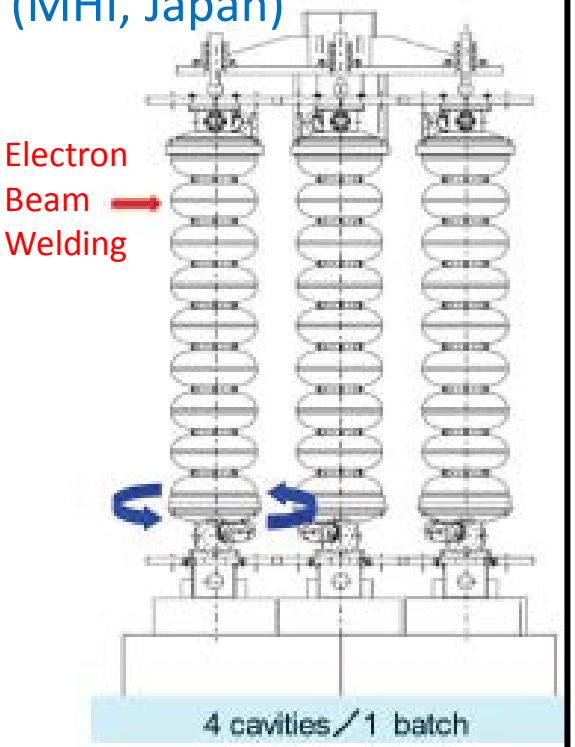
18 sheets x 64 cavities x 1.10
= 1300 sheets (Nb : 1.5 ton)

1300 sheets → about one year

Fabrication of 9-cell Nb cavities (by MHI)

Mitsubishi Heavy Industries (MHI, Japan)





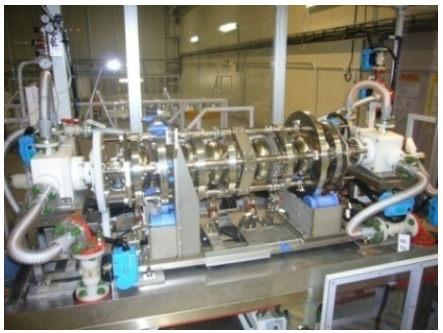
T. Yanagisawa et al. SRF2013, Paris, France (2013), MOP055

4 cavities / 2 weeks
8 cavities / month
80 cavities / year

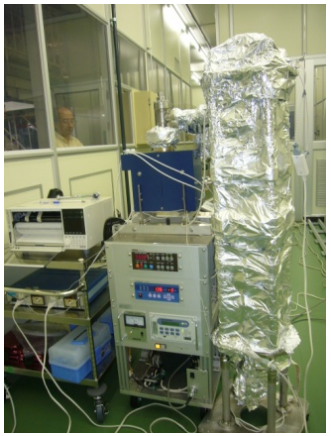
64 9-cell cavities
→ about one year

Surface preparation & Cavity tests (at STF/KEK)

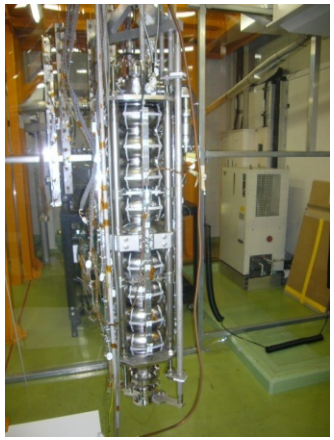
Vertical Test Cycle at STF/KEK



EP (Electro-Polishing) device x 2



Assembly in CR, Baking stand x 2



Hanging stand x 4

VT (Vertical Test) cryostat x 2

2 V.T. / week
80 V.T. / year

64 cavities
→
about one year

Vertical tests at STF

TIG weld with He Jacket

Cavity unit with Jacket
at 1.25 times of design pressure
(test with He gas : 0.25 MPa)

Cavity string assembly in clean room

Cryomodule Assembly (at STF/KEK)

Four 9-cell cavities / Cryomodule

Cavity string assembly
1+1 week

Cold-mass assembly
2 week

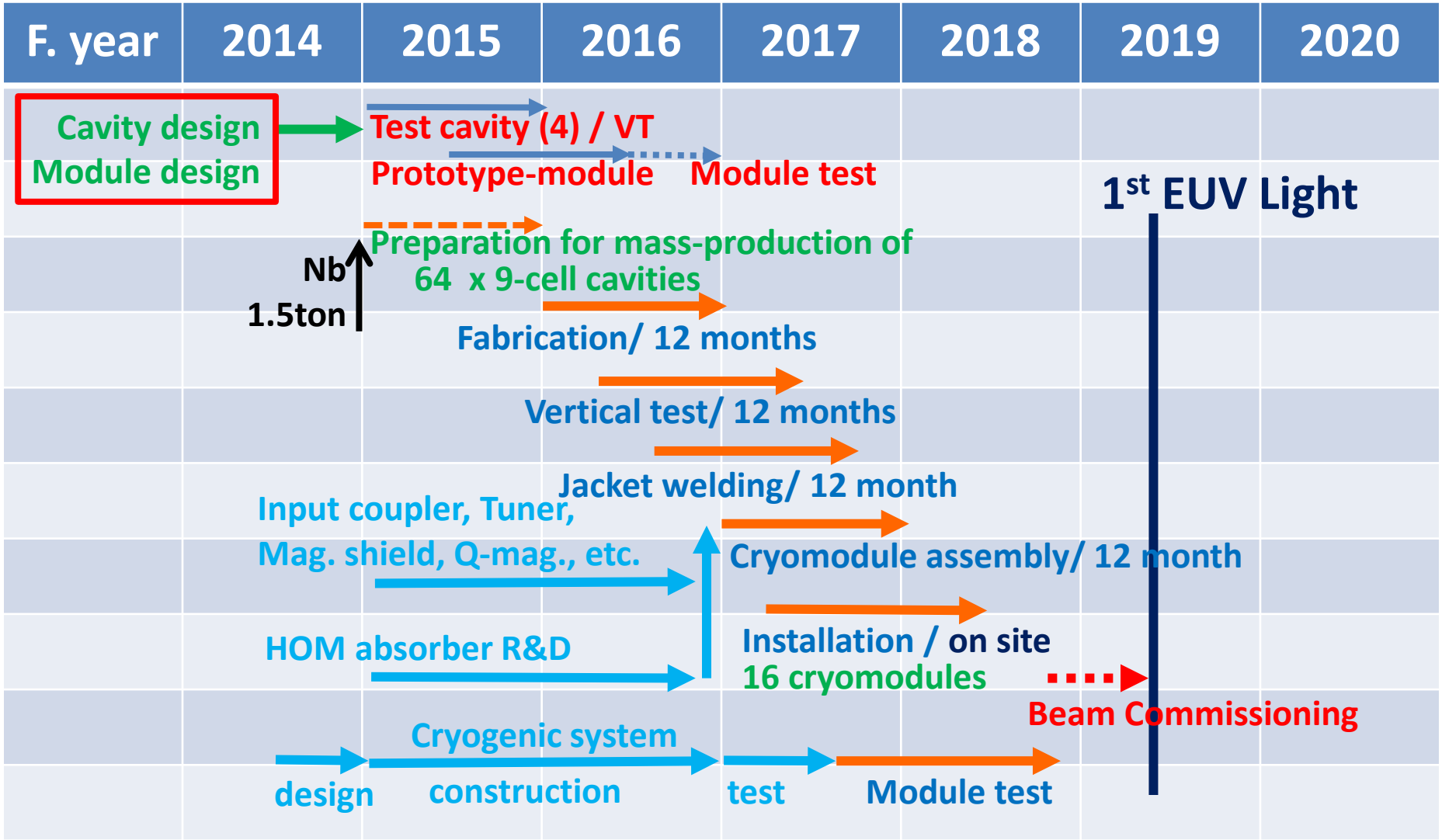
1 CM / 6 weeks
8 CM / year
x 2 lines by overlap
= 16 CM / year

16 Cryomodules
including 64 cavities
→ about one year

Insertion into vacuum vessel
1 week

Installation of input couplers
1 week

4. Construction plan of Prototype ERL for EUV/FEL



5. Summary

Message to EUV-Lithography Community

- EUV light source by using ERL is technically available in power levels around 10 kW, presently.
- Infrastructures for construction of prototype ERL for EUV/FEL is ready at KEK, and the realistic construction schedule of the prototype ERL for EUV/FEL was shown.
- First EUV light could be possible in 2019,
  if the R&D is started just now.

Thank you for your attentions !